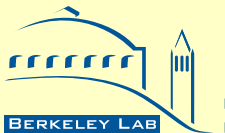
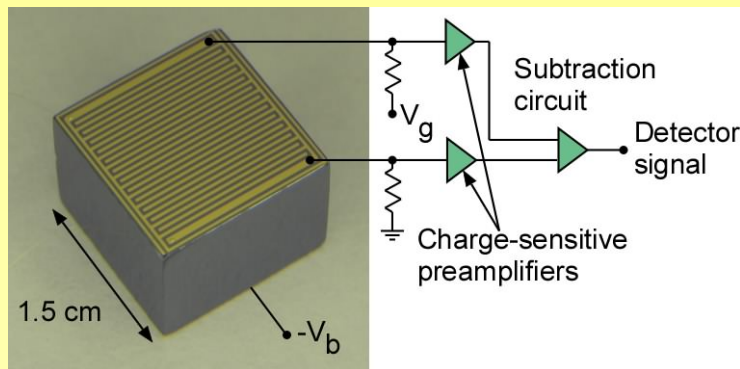


Radiation Detector Materials Research at LBNL

- 1) Development of Advanced CdZnTe Coplanar-Grid Detectors
- 2) Development of AlSb Ambient Temperature Radiation Detectors
- 3) Semiconductor Radiation Detection Materials: High Throughput Screening and Database Development
- 4) Limiting Factors in Scintillator Energy Resolution
- 5) Systematic Search for New Ce-activated Lanthanum Scintillators
- 6) High-Throughput Discovery of Improved Scintillation Materials
- 7) ZnO(Ga) Alpha Detectors for Tagged Neutron Beams



1) Development of Advanced CdZnTe Coplanar-Grid Detectors



CdZnTe coplanar-grid detector along with the simple electronics required for operation

Research Team

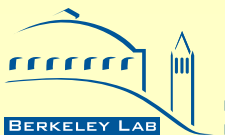
Mark Amman (PI), Paul Luke

Technical approach:

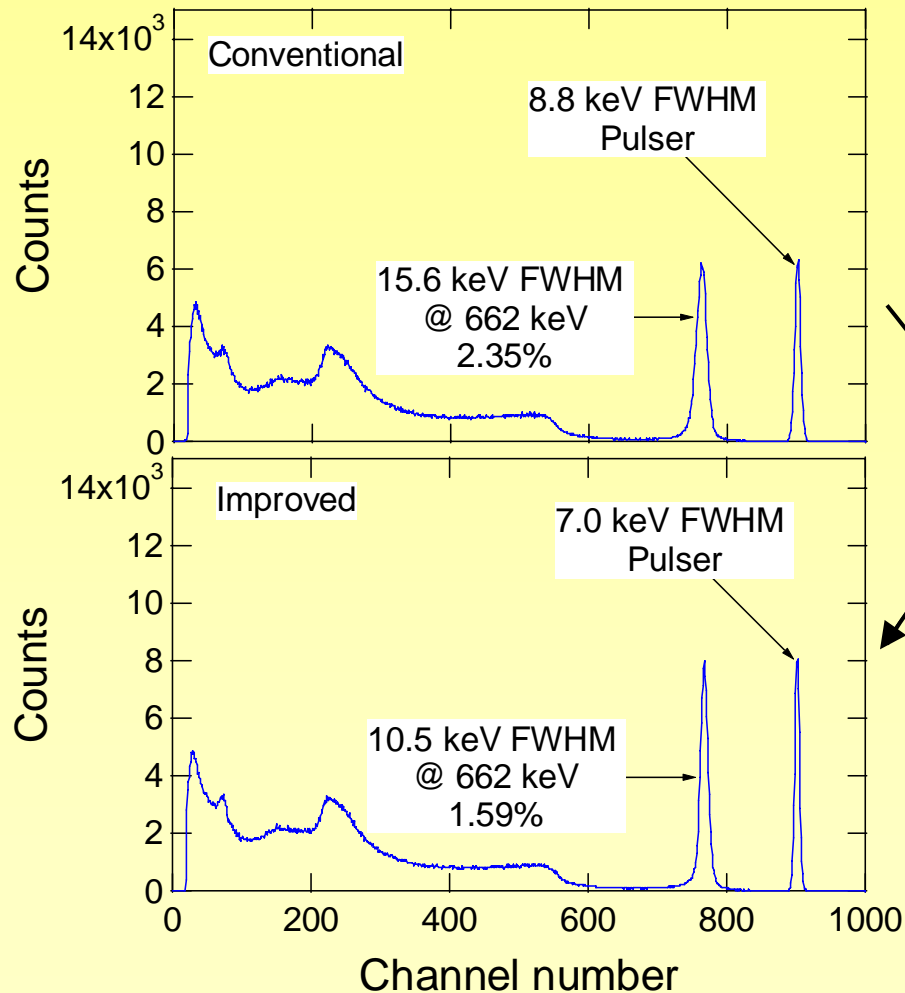
Develop advanced CdZnTe coplanar-grid detectors through a comprehensive program of fundamental device studies, fabrication process development, device modeling, material evaluation, and electronics improvement

Performance targets:

- Energy resolution $<1\%$ @ 662keV (0.5% goal)
- Single detector volumes $>3\text{cm}^3$ (array to achieve larger volumes)
- Near full-volume efficiency
- Near Gaussian peak shapes



1) Development of Advanced CdZnTe Coplanar-Grid Detectors

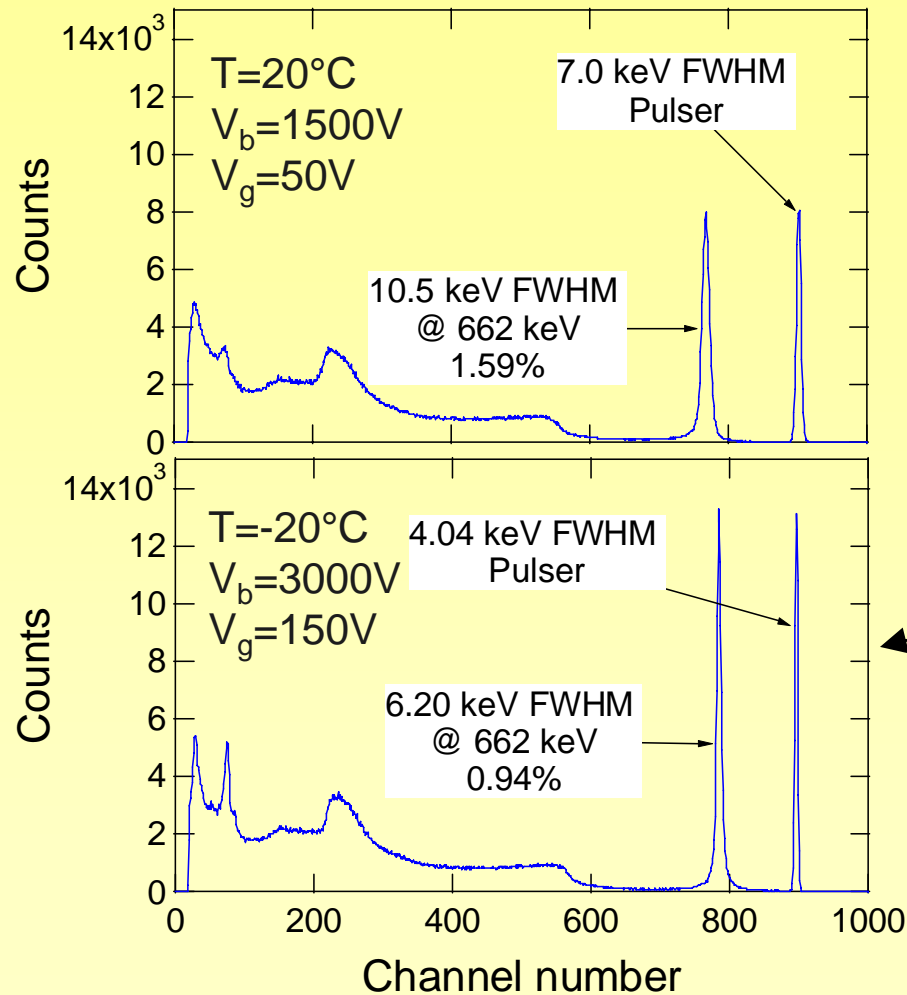


1 cm³ CdZnTe CPG detector
T=20°C

Reduced noise and better
charge collection obtained
through improved detector
fabrication



1) Development of Advanced CdZnTe Coplanar-Grid Detectors



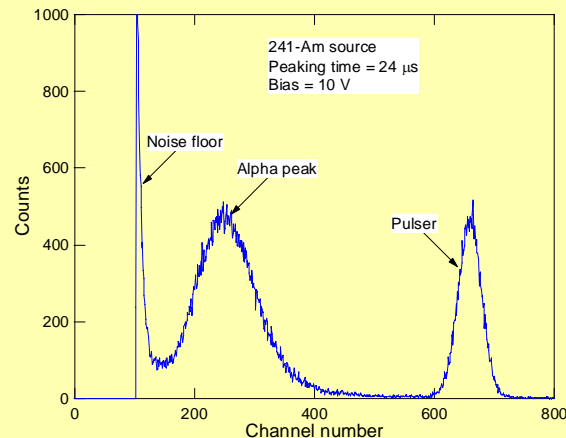
1 cm³ CdZnTe CPG detector

Similar performance achieved with 2.3 cm³ detector

One goal is to obtain this performance at room temperature through improvement in electrical contact technology and surface processing



2) Development of AlSb Ambient Temperature Radiation Detectors



Research Team

Principal Investigator(s):

LBNL: PI – Paul Luke, Co-PI – Edith Bourret

LLNL: PI – Kuang Jen Wu

Supporting Investigators:

W. Bonner, Crystallod, NJ

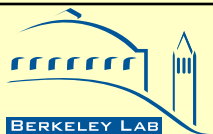
R. Hockett, Evans Analytical Group, CA

Technical Challenges:

- ◆ Grow AlSb single crystals free of macro defects
- ◆ Characterize and identify defects affecting detector performance.
- ◆ Improve material processing and growth parameters to reduce defects.
- ◆ Design and build next-generation crystal pullers.
- ◆ Develop detector fabrication processes.
- ◆ Achieve gamma-ray detection and spectroscopy.

Planned Accomplishments

- ◆ FY2006 – achieve single-crystal growth; evaluate crucibles for zone refining; characterize defects; develop detector fabrication techniques.
- ◆ FY2007 – identify relevant defects and their segregation behavior; improve crystal growth and purity; demonstrate gamma-ray detection.
- ◆ FY2008 – produce low-defect single crystals; improve detector fabrication; achieve gamma-ray detection with good energy resolution.



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2) Development of AlSb Ambient Temperature Radiation Detectors

“Single carrier” detectors (CdZnTe model)

- Require low $\mu\tau_h$ and high $\mu\tau_e$
- Require single-carrier sensing (Co-Planar Grid)
- Lower risk
- Shorter development time
- Can approach Ge performance in small sizes (higher readout capacitance)

AlSb is a candidate as a “Dual carrier” detectors (Ge model)

- Require very high $\mu\tau_h$ and $\mu\tau_e$ ($\sim 10^{-1} \text{ cm}^2/\text{Vs}$).
- Higher risk
- Longer development time
- Can approach Ge performance in larger sizes (lower readout capacitance)

AlSb is the only known material with the necessary high hole and electron mobilities for high resolution room temperature detection



3) Semiconductor Radiation Detection Materials: High Throughput Screening and Database Development



Thin-film
laser ablation

An example of material library fabricated using high throughput combinatorial material screening approach

Research Team

S. S. Mao, K.-N. Leung, P. Luke, R. Russo, W. Walukiewicz, P. Yu
(all researchers are LBNL scientists)

Core Technology

High throughput “combinatorial” semiconductor material fabrication, supported by systematic material processing, characterization, and theoretical modeling.

Fabrication – Characterization – Modeling – Database

Technical Challenges:

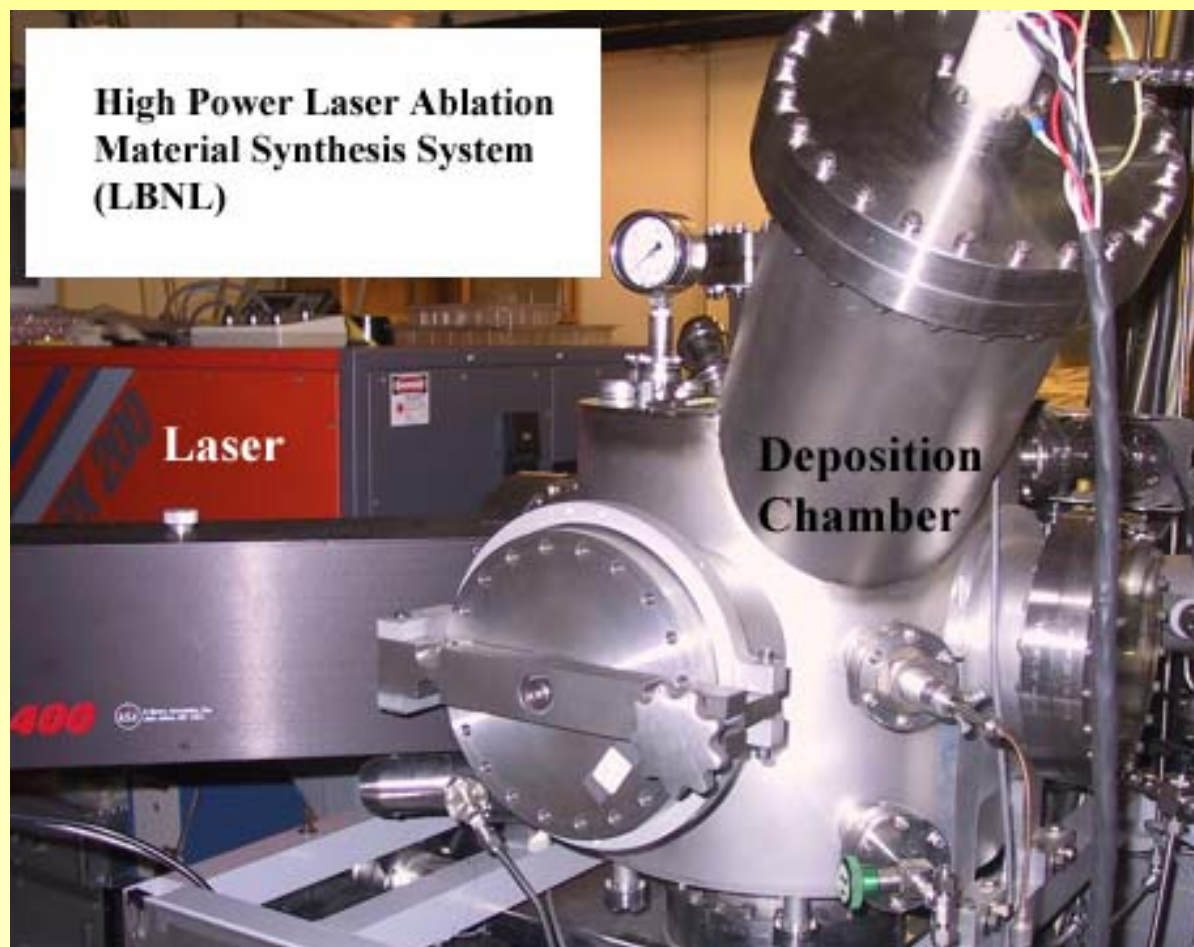
- ◆ There is no known high atomic number or high neutron cross-section semiconductor materials that simultaneously have (1) large enough energy band-gap that ensures low radiation detector leakage current, and (2) large carrier mobility-lifetime product that enables high charge collection efficiency.
- ◆ There is no systematic theoretical prediction of energy band gaps and carrier transport properties of high atomic number or high neutron cross-section semiconductor materials.

Planned Accomplishments

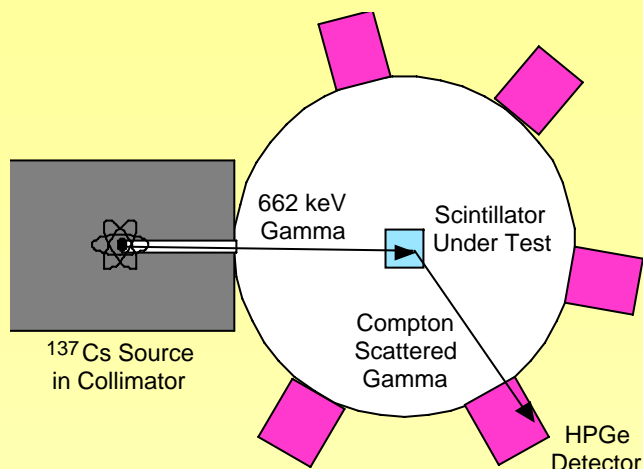
- ◆ FY2006 – 200 new binary and ternary high-Z materials of different compositions tested as potential γ -ray detector materials.
- ◆ FY2007 – 1000 new binary and ternary high-Z materials of different compositions tested as potential γ -ray detector materials.
- ◆ FY2008 – 1000 new ternary high-Z and 800 new B-containing materials of different compositions tested as potential γ -ray and neutron detector materials.



3) Semiconductor Radiation Detection Materials: High Throughput Screening and Database Development



4) Limiting Factors in Scintillator Energy Resolution



Research Team

Principal Investigator:
William W. Moses, LBNL

Supporting Investigators:
Stephen E. Derenzo, Woon-Seng Choong, & Martin Janecek, LBNL.
Nick Park, DOE Undergraduate Summer Intern.

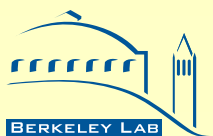
Collaborators on Compton Coincidence Project:
John Valentine, *et al.*, LLNL

Technical Challenges:

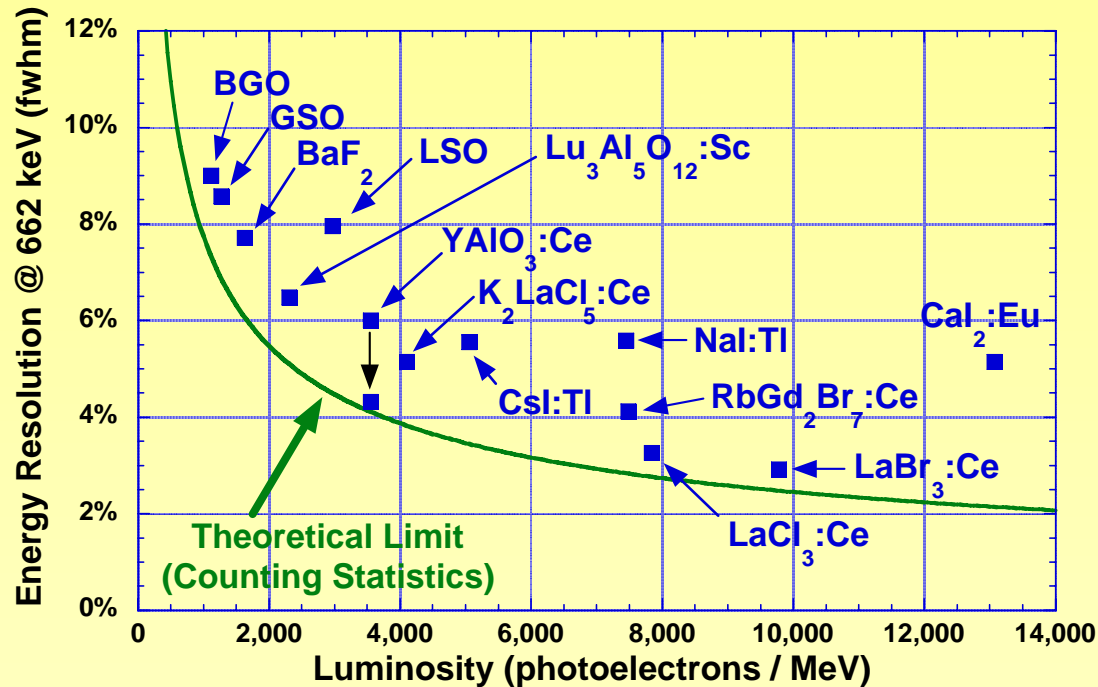
- Better theoretical understanding of scintillator “non-proportionality,” which limits its energy resolution. Construct apparatus to measure non-proportionality and develop Monte Carlo methods to simulate the underlying physics.
- Improve tools for modeling light collection uniformity in scintillators, which improves energy resolution. Construct device to measure reflectance, modify & validate MC simulation.

Planned Accomplishments

- FY2006 – Design and begin construction of Compton Coincidence apparatus for measuring energy resolution. Design and construct apparatus for measuring reflectance.
- FY2007 – Complete construction of Compton Coincidence apparatus and make measurements. Make reflectance measurements.
- FY2008 – Develop and validate Monte Carlo simulation for both tasks.



4) Good Energy Resolution Requires: High Luminosity, Proportional Response, Optical Clarity



From P. Dorenbos, *Nucl Instr Meth*, A486, pp. 208-213, 2002.

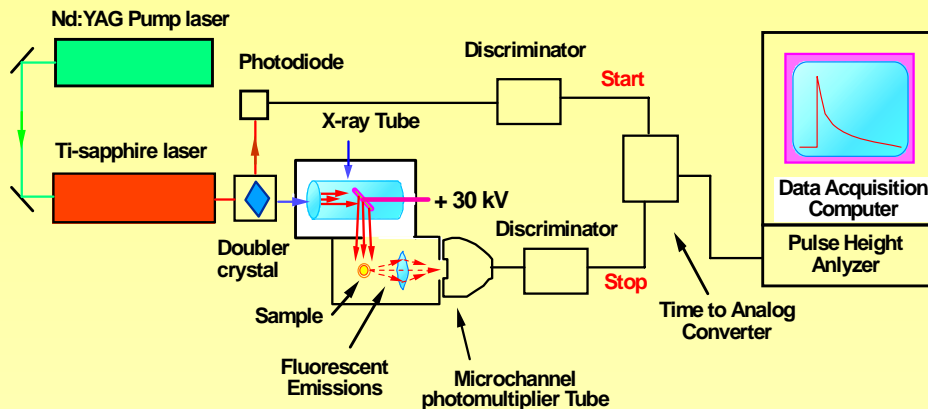
Gamma rays interact by producing recoil electrons with random energies.

Want light output to be proportional to energy deposited, even for low energy electrons.

By measuring luminosity and proportionality, this project can determine whether a new scintillator material is capable of good energy resolution before making an effort to grow large, clear crystals.



5) Systematic Search for New Ce-activated Lanthanum Scintillators



Research Team

Principal Investigator(s):
Stephen E. Derenzo, Edith Bourret-Courchisne

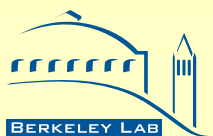
Supporting Investigators:
Scott Taylor, Yetta Porter-Chapman, Marvin Weber

Technical Challenges:

- Synthesize all known lanthanum compounds as crystalline powders
- Many such compounds must be prepared in a dry atmosphere
- Avoid false negatives

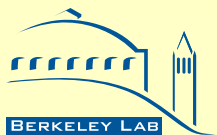
Planned Accomplishments

- Systematic screening of a large number of lanthanum compounds
- Acquire and test small crystals of all promising compounds



5) Systematic Search for New Ce-activated Lanthanum Scintillators

- Lanthanum has a high atomic number (57) which is important for absorbing gamma rays.
- Lanthanum has about 100 times less natural radioactivity than lutetium (about 1 count/s/cm³ vs. 100 counts/s/cm³).
- Lanthanum scintillators can be used to detect gamma rays in a neutron environment, unlike gadolinium.
- Lanthanum has a rich chemistry and there are many hundreds of lanthanum-containing compounds that have not been explored as scintillator radiation detectors.
- Some of the brightest known scintillators (cerium-activated LaBr₃ and LaCl₃) contain lanthanum.
- A large fraction of the La³⁺ ions can be replaced with luminescent Ce³⁺ ion since their covalent and ionic sizes are almost identical. This allows a wide range of cerium concentrations to be explored.



6) High-Throughput Discovery of Improved Scintillation Materials



Research Team

Principal Investigator(s):

Stephen E. Derenzo, Edith Bourret-Courchisne

Supporting Investigators:

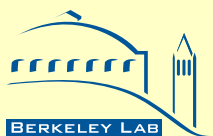
Scott Taylor, Yetta Porter-Chapman, Andrew Canning, Lin-Wang Wang, Ross Buchko, Marvin Weber, William Moses

Technical Challenges:

- Develop high-throughput techniques for synthesizing the maximum range of compounds as crystalline powders
- Develop high-throughput techniques for characterizing scintillator materials
- Avoid false negatives

Planned Accomplishments

- Synthesize and characterize hundreds of compounds as scintillation radiation detectors
- Correlate crystal and electronic structure with scintillation performance
- Acquire and test small crystals of all promising compounds

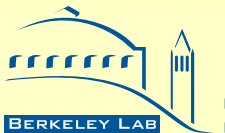


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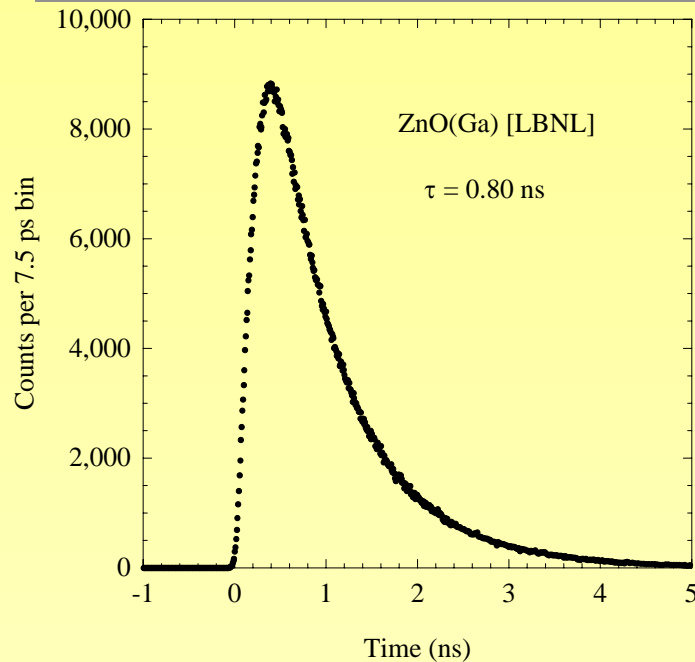
6) High-Throughput Discovery of Improved Scintillation Materials: Strategy

- 1) Build database of thousands of known crystalline materials plus "designer compounds"
- 2) Select candidates and synthesize using robotic dispenser and furnace arrays
- 3) Characterize crystal phase using x-ray diffraction
- 4) Characterize as scintillators using x-ray excitation
- 5) Compute electronic structure- relate to scintillation performance
- 6) Fold measurements into database to refine candidate selection
- 7) Test crystals of best as scintillation detectors

In theory, a proportional scintillator with 100,000 photons @ 662 keV coupled to a high quantum efficiency photodetector could achieve 1% fwhm.



7) ZnO(Ga) Alpha Detectors for Tagged Neutron Beams (BES; Applied Signals, Inc.)



Research Team

Edith Bourret-Courchesne, Stephen E. Derenzo,
Marvin J. Weber

Collaborators

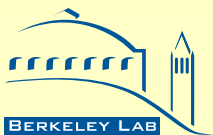
John Neal, John Mihalcz, Lynn Boatner, ORNL
Paul Hurley, Jim Tinsley, STL Battelle Nevada
Dale Turley, STL Battelle Santa Barbara
Sveinn Thorderson, Applied Signals Inc.
David Koltick, Purdue U.

Technical Challenges:

- Identify radiative centers and enhance their concentration
- Identify non radiative centers and eliminate their effect on luminosity
- Understand the ultra-fast scintillation mechanism in this semiconductor scintillator

Planned Accomplishments

- Increase the luminosity 3-10 fold
- Provide alpha detection material for collaborators
- Apply concepts learned to heavy semiconductor scintillators (e.g. PbI_2)



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7) Associated Particle Imaging

